General Relativity Conflict and Rivalries

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Einstein's Polemics with Physicists

By

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“When I accompanied him [Einstein] home the first day we met, he told me something that I heard from him many times later: ‘In Princeton they regard me as an old fool.’ (‘Hier in Princeton betrachten sie mich als einen alten Trottel’.) […] Before he was thirty-five, Einstein had made the four great discoveries of his life. In order of increasing importance they are: the theory of Brownian motion; the theory of the photoelectric effect; the special theory of relativity; the general theory of relativity. Very few people in the history of science have done half as much. […] For years he looked for a theory which would embrace gravitational, electromagnetic, and quantum phenomena. […] Einstein pursued it relentlessly through ideas which he changed repeatedly and down avenues that led nowhere.

The very distinguished professors in Princeton did not understand that Einstein’s mistakes were more important than their correct results. Einstein, during my stay in Princeton, was regarded by most of the professors there more like a historic relic than as an active scientist”.

Leopold Infeld, “As I see It”, *Bulletin of the Atomic Scientists*, 1965, 9.

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From Zurich to Berlin

General Relativity between 1912 and 1916

PREFACE

We can pose many thought-provoking questions in regards to Einstein's achievements: Was the theory of general relativity the invention of Albert Einstein, who would close himself off in an office with his violin, pipe and a pile of papers? Or, was it a culmination of Einstein's multilateral interactions with other scientists? And, to what extent did Einstein's loyal friend from school, Marcel Grossmann, contribute to the mathematics of the general theory of relativity? Other questions focus on the general topic of how scientists debate and, in the process, modify their ideas. Was the theory of general relativity a physical-conceptual theory containing innovations in a synthesis developed from his interactions with friends and colleagues? Was the theory of general relativity a product of debates and conflicts between Einstein and other scientists?

In this book I present an approach that focuses on the work of an individual scientist, Albert Einstein, and his interaction with and response to many eminent and non-eminent scientists. According to this approach, the ongoing discussions between Einstein and other scientists have all contributed to the edifice of general relativity and relativistic cosmology. Mara Beller argues that, the scientists, with whom Einstein implicitly or explicitly interacted, form a complicated web of collaboration (Beller 1999).

I have analysed the works of those scientists who were, in any way, connected to the development of the general theory of relativity and relativistic cosmology, focusing on their implicit and explicit responses to Einstein's work.

This analysis has uncovered latent undercurrents, which could not have been exposed by means of tracking the intellectual pathway of Einstein to his general theory of relativity. The new interconnections and meanings disclosed have revealed the central figures who influenced Einstein during his development of the general theory of relativity and in the construction of the edifice of relativistic cosmology; this includes the themes, outlooks, suppositions and contributions of these scientists as opposed to Einstein's *Weltanschauung* (worldview).

Furthermore, current history presupposes that all the efforts invested by physicists like Max Abraham, Gunnar Nordström, Gustav Mie and David Hilbert, which presented differing outlooks and discussions revolving around the theory of gravitation, were relegated to the background. Thus, those works that did not embrace Einstein's overall conceptual concerns (these primarily included the heuristic equivalence principle and "Mach's ideas") were rejected, and authors focused on Einstein's prodigious scientific achievements.

I emphasise the limits of the simplistic hero worship narrative, and the associated problems tracing Einstein's intellectual pathway to the general theory of relativity. I demonstrate in this book that one should not discard Einstein's response to the works of Max Abraham, Gunnar Nordström, Gustav Mie, Tullio Levi-Civita, David Hilbert and others. On the contrary, Einstein's responses to these works constitute a dynamic (explicit or implicit) interaction that assisted him in his development of the general theory of relativity.

The issue of a mutual interaction and inspiration profoundly touches central historiographic questions and topics, such as: What is the character and nature of innovations? Indeed, a penetrating look reveals a picture that attests to the fact that the general theory of relativity was the product of a much more complex process. Therefore, by combining the creative processes and discoveries of numerous scientists with that of Einstein, we can better understand their influence on Einstein's path to the general theory of relativity. In other words, the construction of the historical account should reflect Einstein's interactions with other scientists.

By incorporating this perspective, the historical account of the development of the theory of relatively diverges from its focus on the creative process of the humble genius who never wore socks, and who would close himself off in an office, claiming "I will a little tink" (Hoffmann 1968; Regis 1987, 20). Rather, this account focuses on Einstein's active interactions with other scientists in Europe and later the United States and their influence on his work.

This leads to the important conclusion that the general theory of relativity was not developed as a single, coherent construction by an isolated, brooding individual; instead, it illuminates the reality that general relativity was developed through Einstein's conflicts and interactions with other scientists, and was consolidated by his creative processes during these exchanges.

After 1917, scientists Willem de Sitter, Sir Arthur Stanley Eddington, Aleksandr Friedmann, Georges Lemaître and several others found in Einstein's general theory of relativity an initial theory from which they developed cosmological models. They elaborated the theory of general relativity until it evolved into a new version that contained cosmological solutions and models not found in Einstein's 1915 and 1916 papers.

By addressing Einstein's response, interaction and competition with these scientists, and the post-1916 responses of other scientists to his work, I wish to shed light on Einstein's way of thinking and organisation of ideas, as well as the impact he had on scientists with whom he interacted, all of which contributed to the construction of the general theory of relativity and relativistic cosmology. Two examples have been provided to support this claim:

1) In 1918 Felix Klein demonstrated to Einstein that the singularity in the de Sitter solution to the general relativity field equations was an artefact of the way in which the time coordinate was introduced. Einstein failed to appreciate that Klein's analysis of the de Sitter solution showed that the singularity could be transformed away. In his response to Klein, Einstein simply reiterated the argument of his critical note on the de Sitter solution. Einstein, however, was usually trusted as the authority on scientific matters. In 1917-1918 the physicist-mathematician Hermann Weyl's position corresponded exactly to Einstein's when he criticised de Sitter's solution; Weyl's criticism revealed the influence of Einstein's authority in physics even on first-rate mathematicians (like Weyl):

In 1922, Erich Trefftz constructed an exact static spherically symmetric solution for Einstein's vacuum field equations with the cosmological term. The Trefftz metric represents a model for a spherical closed (finite) universe, a de Sitter static universe devoid of matter whose material mass is concentrated in just two spherical bodies on opposite sides of the world. Einstein identified a problem with this line element. In 1922 he demonstrated that Trefftz's solution contained a true singularity in the empty space between the two bodies. Consequently, time stands still in the de Sitter empty space between the two masses. This signifies there are other masses distributed between the two masses. Einstein said that Weyl had already shown that many masses existed somewhere in-between the two bodies. Indeed, to keep the two bodies apart at a constant distance (in a static closed world), Weyl had to introduce a true singularity at the mass horizon (somewhere in the empty space between the two bodies). He introduced the true singularity and concluded that a zone of matter exists between the two bodies. Weyl was misled by the apparent de Sitter singularity into believing that the mass in de Sitter's world is distributed on a mass horizon, and this induced him to introduce a true singularity. Weyl therefore omitted part of the space-time around the horizon and replaced it by the Schwarzschild interior solution of Einstein's field equations with the cosmological constant. Instead of removing the apparent de Sitter singularity, Weyl introduced a true singularity by joining two solutions: the de Sitter and Schwarzschild interior solutions (Goenner 2001, 111-112).

In March 1918, before publishing the book *Space-Time-Matter*, Weyl instructed his publisher to send Einstein the proofs of his book. In the same month, Weyl also instructed his publisher to send David Hilbert the proofs of his book. Hilbert looked carefully at the proofs of Weyl's book but noticed that the latter did not even mention his first Göttingen paper from November 20, 1915, "Foundations of Physics". Though Weyl mentioned profusely Einstein's works on general relativity, no mention was made of Hilbert's paper. Einstein received the proofs page-by-page from the publisher and read them with much delight and was very impressed. However, Einstein, an initial admirer of the beauty of Weyl's theory, now raised serious objections against Weyl's field theory. Einstein's objection to Weyl's field theory was Weyl's attempt to unify gravitation and electromagnetism by giving up the invariance of the line element of general relativity. Weyl persistently held to his view for several years and only later finally dropped it.

2) Einstein also seemed to influence Sir Arthur Stanley Eddington when he objected to what later became known as "black holes". In 1922, during discussion sessions at the Collège de France in Paris, Jacques Hadamard questioned Einstein about the Schwarzschild solution to his field equations and its practical relevance for astronomy. In Schwarzschild's solution a singularity exists at $r = 0$ (a quantity that becomes infinite). Hadamard was questioning what would actually happen in reality if, mathematically, the singularity could really become infinite in our world? Could this practically and physically occur? While it may not happen in our solar system, it may certainly be possible elsewhere in the universe.

This question reportedly embarrassed Einstein. He said that if the radius term could really become zero or infinite (be singular) somewhere in the universe, then it would be an unimaginable disaster for his general theory of relativity. Einstein considered this a catastrophe, and jokingly called it, the "Hadamard catastrophe". Hence, according to Einstein, the

Schwarzschild singularity, $r = 0$, characterised a catastrophic region. He did not think the "Hadamard catastrophe" was possible, and he did not want to think about the physical effects of this case.

In 1939, Einstein repeated his previous claims, speaking clearly against the Schwarzschild singularity: He stated the impossibility of the Schwarzschild singularity, it did not exist in physical reality.

Eddington, however, seemed to have been influenced by Einstein's viewpoint. In his controversy during the Royal Astronomical Society meeting of 1935 with Subrahmanyan Chandrasekhar, Eddington argued that various accidents may intervene to save a star from contracting into a diameter of a few kilometres. This possibility, according to Eddington, was a *reductio ad absurdum* of the relativistic degeneracy formula. Chandrasekhar later said that gravitational collapse leading to black holes is discernible even to the most casual observer. He, therefore, found it hard to understand why Eddington, who was one of the earliest and staunchest supporters of the general theory of relativity, should have found the conclusion that black holes may form during the natural course of the evolution of stars, so unacceptable.

However, it is very reasonable that Eddington, who was one of the earliest and staunchest supporters of Einstein's classical general relativity, found the conclusion that "black holes" were so unacceptable, because he was probably influenced by Einstein's objection to the Schwarzschild singularity.

Einstein's 1929 new unified field theory was based on distant parallelism. In May 1929, Einstein received two letters from Élie Joseph Cartan pointing out that Einstein's basic mathematical idea of distant parallelism had been previously worked out by him (Cartan) in great detail in several publications, and that he had even explained the idea to Einstein when they met briefly in Paris in the spring of 1922 at Jacques Hadamard's home. Cartan explained to Einstein that in his 1922 articles devoted to the new theory of general relativity he had introduced the notion "tele-parallelism". It was a special case of a more general notion of the Euclidean connection that he (Cartan) had already advanced and published when Einstein gave his 1922 lectures at the Collège de France. Einstein confessed that he had understood nothing of all the explanations that Cartan had given him in Paris in 1922, still less was it clear to him how they could be made of any use to physical theory. Einstein nevertheless told Cartan that the manifolds he himself had used in his unified field theory were a special case of those studied by Cartan.

Einstein was a rebel and cynic. Characteristically, he was personally unconcerned about the priority question and immediately sprang into action, insisting that this issue had to be rectified. He puzzled over what to do and what to write that would satisfy all just claims. Finally, on Einstein's invitation, Cartan wrote an historical note explaining distant parallelism and the matter was settled. Indeed in 1929, Einstein wrote an exposition of his unified field theory for the journal *Mathematische Annalen*. It was published together with Cartan's essay about the history of distant parallelism.

Einstein, however, was more than delighted to find a very able mathematician such as Cartan interested in his unified field theory, because almost all physicists believed that a fundamental description of physical reality was not possible on the basis of his unified field theory. He employed Cartan's mathematical abilities to answer a series of mathematical queries regarding distant parallelism and Einstein's proposed field equations. Cartan was very pleased that Einstein introduced him to his new research on his unified field theory and thanked him for the trust he put in his abilities as a mathematician.

In this book I discuss Einstein's work on unified field theory that deals with the synthesis of gravitation and electromagnetism. I do not discuss the quantum aspects of the theory.

In 1917 and 1918 the mathematical tools of classical general relativity were elaborated by Levi-Civita and Weyl. They introduced the concept of parallel transport in a Riemannian space as a means of giving an invariant interpretation to the curvature of space. One thinks of particles as moving along geodesic lines in curved, four-dimensional space-time. An affine connection defines the amount of curvature of geodesic lines.

According to Einstein, the general theory of relativity assumes its simplest form when expressed in a generally covariant form. However, in 1923 Élie Cartan formulated Newtonian theory of gravity as a geometric-dynamical theory and provided a generally covariant formulation of Newtonian gravity in space-time – in terms of an affine connection. It is thus possible to redo Newtonian gravity as a theory of curved space-time. Furthermore, the Newton-Cartan theory is written in a generally covariant form as in Einstein's theory of general relativity.

Suppose we possess a generally covariant formulation of both theories – Einstein's general relativity and Newtonian non-relativistic theory.

Einstein explained that Newtonian physics ascribes independent and real existence to space and time, i.e. Newtonian physics assumes a fixed, non-dynamical background space-time structure. General relativity, unlike Newtonian physics and even special relativity, is a background-independent theory. In general relativity, "there is no such thing as an empty space, i.e. a space without field". Furthermore, space-time does not claim existence on its own, but only as a structural quality of the field (Einstein 1952, 155, 176). Space-time is dynamical, and ceases to exist when a singularity is reached. Hence Einstein's general theory of relativity is a dynamical background-independent theory.

John Stachel calls our attention to the fact that in general relativity, the behaviour of measuring rods and clocks (chrono-geometry, i.e. in general the metric) is determined by the inertio-gravitational field. Both the chrono-geometrical and the interio-gravitational structures are dynamical fields. Wherever there is a chrono-geometric structure there is always also an affine inertio-gravitational structure. Chrono-geometrical and inertio-gravitational structures obey field equations coupling them to each other and to all other physical processes. Thus physical processes do not take place in space-time. Space-time is just an aspect of the totality of physical processes. In Newtonian physics, however, the measurement of time and space is unaffected by the presence of an inertio-gravitational field. We thus define compatibility of chronometry and geometry with the inertio-gravitational field (Stachel 2002, 2007b, 429).

In conclusion, I would like to present a more balanced historical account of the development of the general theory of relativity and relativistic cosmology; an account that will reflect the complicated interactions leading to the solidifying of Einstein's general theory of relativity and cosmology.

The main conclusion of my essay is that if we take Einstein's interactions with his colleagues and friends into account, we may arrive at a revised historical explanation of Einstein's general relativity and of relativistic cosmology. Carefully examining the historical progression that led to the theory of relativity reveals pluralistic debates and interactions, based on different aesthetic, philosophic and scientific presuppositions that were dominant in influencing Einstein during his development of the general theory of relativity. In this book I examine Einstein's interactions and debates with several scientists between 1912 and 1948.

It should be noted that the number of physicists actively engaged in research in general relativity remained small between 1925 and 1955. Referring to those years, Peter Bergmann once noted: "You only had to know what your six best friends were doing and you would know what was happening in general relativity" (Pais 1983, 268). Jean Eisenstaedt has characterized the period that extended from 1925 to 1955 as the "low water mark" of general relativity (Eisenstaedt 1989). Until 1955 the relativity community had a strange mix: There was a small group of specialized physicists, Einstein's friends and assistants and a small group of specialized astronomers/cosmologists and mathematicians (who became friends and colleagues of Einstein's). This state of affairs lasted until the 1955 Bern conference marking the Jubilee (50th anniversary) of Einstein's theory of special relativity (Kennefick 2007, 174-175). Einstein had an aversion to pomp and ceremony and did not feel the need to celebrate his achievements. He did not live long enough to participate in this conference. Indeed, the conference was held in July 1955 (shortly after Einstein died in April 1955). Although it was decided to have the conference in Bern where Einstein had published his special relativity, the papers presented were largely devoted to general relativity: cosmology, unified field theory and methods of solutions of the field equations. The conference was attended by physicists interested in working in relativity theory and it would later come to be known as GR0, the zeroth conference in a series which continues to this day.

This book is loosely based on my PhD thesis that was written between 1995 and 1998 at the Hebrew University of Jerusalem. Although little of it remains, I would like to thank the late Prof. Mara Beller, who was inspirational as my PhD supervisor. The book has benefited greatly from my endless conversations with her at the Van Leer Jerusalem Institute during my PhD studies. I would also like to thank Prof. Asa Kasher of the Tel-Aviv University for believing in me.

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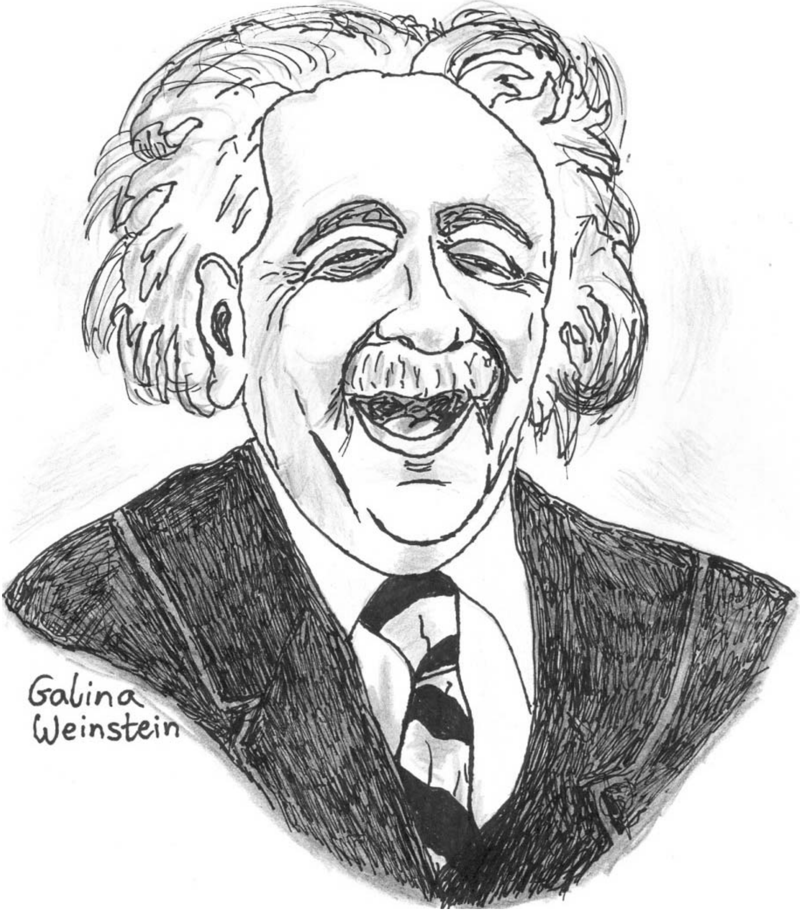
Galina Weinstein, November 2015


Galina
Weinstein

CHAPTER ONE

FROM ZURICH TO BERLIN

1. Einstein and Heinrich Zangger

Working alongside Einstein at the patent office was his close friend Michele Besso. During his employment there, Einstein enjoyed considerable freedom in what he called the *worldly cloister*, where he spent considerable time *ruminating* and pondering his best ideas; *brooding* upon his theories, and inventing his most beautiful concepts. During this time at the patent office, he contemplated the problem of gravitation, and in doing so, invented a new thought experiment: A man falling freely from a roof under the influence of gravity. He published his first paper on the topic on December 4, 1907, "On the Relativity Principle and the Conclusions Drawn from It" (Einstein 1907). When no complicated mathematics entered into the theory, the extension of the 1905 special relativity principle apparently turned out to be quite natural and simple.

Guided by Galileo's principle of free fall, Einstein postulated the principle of equivalence – he assumed the complete physical equivalence of a gravitational field and a corresponding acceleration of the reference system. Using this new principle, with physical reference systems and measuring rods and clocks, he arrived at new results: bending of light rays in a gravitational field, and gravitational redshift (Einstein 1907, 411-462).

Einstein understood the importance of Galileo's law of free fall: All bodies experience the same acceleration in a gravitational field, which can be formulated as the law of the equality of inertial and gravitational mass. He then connected between the Newtonian result of the equality of the inertial mass and the gravitational mass (which was quite accidental from the point of view of classical mechanics) and his principle of equivalence. Equality of gravitational and inertial mass was, therefore, essential for Einstein and played a crucial role in constructing his theory on the basis of the equivalence principle.

Michele Besso introduced Einstein to Heinrich Zangger, a doctor of forensic medicine, the originator of shock treatment, and director of the Forensic Medicine Institute of the University of Zurich.

Zangger was devising a new, experimentally simple method for determining Avogadro's number as an outgrowth of his research on milk as a colloidal system. The method consisted of the microscopic observation of the irregular path, due to Brownian motion, of small mercury droplets falling through a liquid. For advice on the theoretical analysis of this experiment, Zangger turned to a mechanical engineering professor at the Swiss Polytechnic, Aurel Stodola, a specialist in the field of steam turbines and thermodynamics. Like Zangger, he had wide-ranging interests that included physics. A letter from Michele Besso to Zangger, written more than two decades later, suggests that Stodola may have learned of Einstein from Besso, who was one of his students. Aware of Einstein's work in Brownian motion, Stodola directed Zangger to him. Zangger consulted Einstein at the patent office in Bern, where the physicist was then working. Einstein and Zangger became close friends. In time, Einstein, his mother, and the whole Einstein family would be among Zangger's patients (Medicus 1994, 459; Seelig 1954, 129; 1956a, 109). Einstein would write to Zangger about his personal and professional difficulties. He would also tell him his opinions concerning the controversies and polemics he had with physicists like Max Abraham and David Hilbert (see Chapter 2, Sections 2 and 9).

2. From Zurich to Prague

From 1909 Einstein was finally accepted into the academic world, as associate professor at the University of Zurich. This appointment brought him, for the first time, a position with the conventional view of a certain public prestige.

Between 1907 and 1911, Einstein was occupied with research on radiation and the quantum of light, and did not publish papers on gravitation. Nonetheless, he was pondering the problem of gravitation from 1907, during the four years he was working at the University of Zurich, as he himself explained it during the 1933 Glasgow talk, "The Origins of the General Theory of Relativity".

Einstein explained that between 1908 and 1911 he considered his 1907 principle of equivalence, and checked whether this was an indication for an extension of the special principle of relativity to coordinate systems in non-uniform motion with respect to each other, once one wanted to reach a causal theory of the gravitational fields (Einstein 1933; 1934, 252; 1954, 287).

However, in spring 1911 Einstein left his comfortable position at the University of Zurich and moved to the German University of Prague, Karl-Ferdinand University. Philipp Frank explains why Einstein took this step (Frank, 1949, 130-131, 135-137; 1947, 75-79).

From the financial point of view, the position of an associate professor in the University of Zurich was unattractive; his income was no larger than it had been at the patent office. Also, he had to pay for things which gave him no pleasure for life, but which were required by this position.

Although Einstein loved Zurich, he was too busy teaching to undertake decent research at the University of Zurich. Beyond regular teaching, he was occupied with training students, administrative duties, and financial problems. Thus, progress on his research on gravitation slowed, and he concerned himself with the quantum problem and heavy administrative and teaching duties.

He would sometimes joke that in the relativity theory he could well put a clock at every point in space (in this way synchronising distant clocks in one reference frame); however, in reality he found it difficult to set up only one clock at one point in space, because he had no time for any research.

Prague boasted two universities, one Czech University and the other a German University. In the fall of 1910, a vacancy arose in the teaching chair of theoretical physics in the German University. The German University was certainly not the center of research in physics, and while Einstein and his first wife Mileva Marić were not thrilled about moving countries, he looked forward to this position and was eager to accept it: This position offered Einstein, for the first time in his life, a full professorship with adequate salary and significant research time.

Indeed, the position was first offered to Einstein. The decision was formally made by the Kaiser of Austria. He deferred, however, the final decision to the Ministry of Education. Physicist Anton Lampa, from the Ministry of Education, was in charge of the selection. Lampa's philosophical *Weltanschauung* (view-point) was for the most part influenced by his teacher, Ernst Mach's, positivistic views. Mach was the first rector of the German University in Prague.

Philipp Frank reports that Lampa was ambitious, and he tried to appear as a man who cared about ethical and modern educational ideas. He wanted to advance freedom of teaching; but there was a big gap between his high ideals and his real scientific abilities. It had always been his dream to climb to the realms of the extraordinary and the genius. Lampa knew he was not a genius. He was thus willing to accept the presence of more important people who could follow Mach. When he thought of candidates for the position to follow Mach's tradition, he had two physicists in mind: Einstein (who never considered himself a genius) and Austrian physicist, Gustav Jaumann (who considered an unrecognised or neglected genius).

Mach denied the reality of atoms, but Einstein (in his work on the Brownian motion) objected to Mach's stand. Einstein would later create his theory of gravitation in Prague, and would be an ardent advocate of Mach's ideas. However, this was not anticipated by Lampa and others, because as a candidate for the position, his work on gravitation was still in its infancy.

At first, the candidates were classified on the basis of their achievements. Einstein had greater achievements to his credit than Jaumann, and so Einstein was the preferred candidate. The Ministry of Education, however, first offered the position to the "neglected genius", Jaumann, since the government preferred to appoint Austrians rather than foreigners. Jaumann, offended by Einstein's preferred status, rejected the offer. He told the minister, that if Einstein was the preferred candidate with greater achievements, then he would have nothing to do with a university that ignores the true merit. The government thus overcame its aversion to foreigners and offered the position to Einstein.

In Einstein's case, therefore, the background to this appointment was typical in many ways, because the personal sympathies and antipathies of the deciding people played a certain role in the decision.[1]

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[1] A similar incidence had already occurred to Einstein in 1908 with the position at the University of Zurich. Alfred Kleiner had persuaded Friedrich Adler to accept the position. The faculty at the University of Zurich was not eager to accept Einstein the Israelite, who had no understanding of how to get on with important people. So they accepted Adler first; however Adler had found a more interesting

Lampa received a letter of recommendation from Max Planck who wrote on Einstein's work on the theory of relativity that it "probably exceeds in audacity everything that has been achieved so far in speculative science and even in epistemology; non-Euclidean geometry is child's play by comparison". Recommending Einstein for the position in Prague, Planck went on to compare Einstein to Copernicus (Pais 1982, 192).

Einstein was appointed to the German University of Prague. However, as a Jew not everything went smoothly, and he was forced to confront his religious status. In 1896 he renounced his legal affiliation to the Jewish religious community and thus become *konfessionslos* (without religion). Imperial Austrian authorities would not accept claims to be *konfessionslos*, which he had signified on his Swiss citizenship a decade earlier (in 1901). To avoid this difficulty, Einstein stated he was of the Jewish religion, and in the questionnaire that he had to fill out he simply wrote his religion was "of Mosaic faith", as Jewish was then called in Austria (Stern 1999, 102-103).

Einstein moved to Prague as a full professor at end of March 1911. Just before that in January 1911 he received an invitation from Hendrik Antoon Lorentz to a lecture in Leiden. In 1892 Lorentz advanced a version of the theory of the electron, based on Maxwell's electromagnetic theory, in order to explain electromagnetic and optical phenomena in bodies at rest and in motion. Lorentz demarcated ponderable matter from the imponderable luminiferous stationary immobile ether. Lorentz published his electron theory in several papers and in his seminal work, *Attempt at a Theory of Electrical and Optical Phenomena in Moving Bodies* (Lorentz 1895), which Einstein read before creating the special theory of relativity. Although Einstein gave up the immobile ether, he always mentioned Lorentz and his influence on his thought.

Einstein corresponded with Lorentz in 1909 on his research on the quantum of light and radiation, and he appreciated Lorentz as a profound thinker (Einstein to Jakob Laub, May 17, 1909, *CPAE* 5, Doc. 160). He was extremely excited to meet Lorentz for the first time, and he travelled with Mileva to Leiden. Einstein engaged in long conversations with Lorentz after his lecture. Bernard Cohn interviewed the elderly Einstein on Sunday morning in April 1955, two weeks before he died. According to Cohn, Einstein met Lorentz in Leiden through Paul Ehrenfest. He

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job at the German Museum in Munich. Upon Adler's suggestion, the position was awarded to Einstein instead.

remarked that he had admired and loved Lorentz perhaps more than anyone else he had ever known, and not only as a scientist (Cohn 1955).

Frank reports that when Einstein arrived in Prague he was certainly unlike the average professor at the German University. He was *konfessionslos* but became Mosiac (Jewish); he was married to a Slav wife, and was suddenly plunged into a milieu where nationality, race, and religion were burning issues; and he was certainly a little extraordinary among the average professors at the German University in Prague. Everyone was curious to meet Einstein, whose reputation as an extraordinary genius preceded his arrival.

In Prague it was customary for a newly arrived faculty member to visit all his colleagues. Initially, Einstein accepted the advice of Lampa and the mathematician Georg Pick to follow this tradition, and he began his more than forty visits and, at the same time, toured the old city of Prague. However, Einstein was a rebel and cynic; he also had an aversion to pomp and ceremony. He spurned the rules of bourgeois life and opted for bohemian alternatives. He soon began to feel the banality of the boring conversations about trivial matters that took place during these visits, and so refused to continue doing them.

Consequently, the professors whom he had not visited were offended; for the notorious professor had already visited several others. Frank, who later replaced Einstein, explained that the professors whom Einstein did not visit thought he was capricious. Frank said that the true explanation was that these colleagues lived in urban areas of the city that did not interest Einstein, or their names were too far back in the faculty directory. It was pure coincidence. Instead of wasting time with formalities, in Prague, Einstein came back to work on the problem of gravitation. This was typical of Einstein (Frank, 1949, 139-140; 1947, 79).

Generally, Einstein enjoyed his time in Prague, even though life was not as pleasant as it had been in Zurich. He felt alien in Prague, and all drinking water had to be boiled first. The population for the most part spoke no German and was strongly anti-German. The students at the university, too, were less intelligent and industrious as in Zurich, but Einstein said he had a fine Institute with a magnificent library.

In 1911, in Prague, when Einstein returned to intensive work on gravitation, he understood that one could test the theory by experiment. He published his first paper on the topic in June 1911 in the *Annalen der*

Physik, "On the Influence of Gravitation on the Propagation of Light". He began his paper by saying that he was returning to the theme of gravitation, because his previous presentation of the subject did not satisfy him. However, the main reason for returning to the subject was his realisation that the consequence from his 1907 gravitation theory – rays of light, passing close to the Sun, are deflected by its gravitational field – was observable through experimental examination. From September 1911, Erwin Freundlich took upon himself to test the bending of light (Einstein to Erwin Freundlich, September 21, 1911, January 8, 1912, *CPAE* 5, Doc. 287, 336).

In the body of the 1911 paper Einstein returned to Galileo's experimental principle of free fall. He was guided by this experimental principle towards formulating the more mature equivalence principle of 1911. He still did not leave the comfortable framework of the physical frame of references, the system of measuring rods and clocks that gave physical meaning for points in space-time. His new gravitation theory was thus a coordinate-dependent theory (Einstein 1911, 898).

During the months he worked in Prague, he also published two papers discussing the theory of the static gravitational field, the first in February and the second in March 1912: "The Speed of Light and the Statics of the Gravitational Fields" and "On the Theory of the Static Gravitational Fields". In his theory on the static gravitational field Einstein was guided by Galileo's principle of free fall, the equality of inertial and gravitational mass, and the equivalence principle; he also used the same method of research he had used with special relativity: the coordinate-dependent methodology.

His 1911 paper concluded that the velocity of light in a gravitational field is a function of the place. Accordingly, in February 1912, within static gravitational theory, Einstein replaced the gravitational potential by the variable speed of light. Thus, he offered a theory of static fields which violated his own light postulate from the special theory of relativity. In March 1912, he discovered that the equivalence principle is not universally valid: The principle of equivalence is valid only locally.

Einstein's first paper on static gravitational fields also dealt with the uniformly rotating disc. Until 1912, Einstein discussed uniformly accelerated systems; the February 1912 paper was the first time he tried to extend the relativity principle to uniformly rotating systems.

Einstein could not yet formulate his 1912 theory of static gravitational field in terms of Minkowski's four-dimensional space-time formalism. It seems that the reason for not using Minkowski's four-dimensional formalism was Einstein's inability to incorporate the equivalence principle and his basic idea of gravitational potential, which was replaced by the variable speed of light, into Minkowski's space-time formalism.

According to Minkowski, the speed of light is constant. However, any gravitation theory that provides the speed of light in an empty space with an unchangeable value, that is to say, assumes the constancy of the velocity of light, cannot explain the deflection of light near the Sun.

After 1912, Einstein was able to use Minkowski's formalism in his theory of gravitation. He would show that light rays that moved in straight lines signified an affiliation with Euclidean geometry, and deflected light rays signified an affiliation with non-Euclidean geometry.

3. Back to Zurich

Hardly six months after Einstein's departure from Zurich, and his friend and eternal lifesaver, Marcel Grossmann, whose father helped Einstein obtain the position in the patent office in Bern, asked Einstein whether he would be interested in a post at the *Eidgenössische Polytechnische Schule* (Swiss Federal Polytechnic School). Einstein had been a student at the school, which he used to call the *Zürcher Polytechnikum* (the Zurich Polytechnic School or Zurich Polytechnic). The institute was later named the *Eidgenössische Technische Hochschule* [ETH] (Swiss Federal Institute of Technology). While a student at the Polytechnic, Einstein often skipped classes, and failed to attend all required lectures, and used Marcel Grossmann's notes for studying before sitting for an examination. Grossmann had become a professor at the Zurich Polytechnic in 1907 and was appointed dean of mathematics in 1911.

Einstein was happy to exchange Prague for Zurich. He was most certainly inclined, in principle, to accept a teaching position in theoretical physics at the Polytechnic. Pierre Weiss from the Polytechnic approached two very important scientists for recommendations, scientists whom Einstein met in the first Solvay congress in Brussels in 1911 – Marie Curie and Henri Poincaré (Einstein to Grossmann, November, 18, 1911, *CPAE* 5, Doc. 307; Seelig 1954, 154, 162-163; 1956a, 129, 133).

Zangger also fought for Einstein's appointment to the Polytechnic. Zangger learned, probably from Grossmann, that Einstein was unhappy in Prague and wanted to return to Zurich. Although he was a professor at the Medical School of the Cantonal University, Zangger immediately employed his good connections with the federal government on his friend's behalf.

Not all of the professors at the Polytechnic were enthusiastic about the prospect of Einstein's appointment, because it did not fit with their own research priorities and personal ambitions. In particular, the school president, Robert Gnehm, a former chemistry professor, was not in favour of this appointment; although he admitted that Einstein was an eminent scientist, Gnehm felt that he would be an unnecessary luxury. He argued that theoretical physics was already well covered, observing that in the preceding year, for example, there had been courses on the theory of absolute magnetic and electric measurements, the theory of alternating currents, electrical oscillations, electro-mechanics, experimental radioactivity, and ionization and radioactivity. He furthermore noted that Einstein was not a good teacher and that, as a physicist, he would require laboratory space. This was not quite true, since Einstein was occupied with basic principles, that is to say, theoretical physics. In response, Zangger directly contacted one of the federal councilors, Ludwig Forrer, whom he knew personally.

Zangger, who had attended several hours of Einstein's lectures agreed he was not a smooth orator, and therefore not a good teacher for students who were too lazy to think and who only wanted to memorise their work. However, he felt that high level students would find in Einstein a first-class teacher (Medicus 1994, 460-461).

Thus Einstein was finally elected to the office of Professor of Theoretical Physics in the Zurich Polytechnic.

Einstein was a celebrity by the time he left Prague. Newspapers speculated about reasons for his short sixteen-month stay in Prague. The political landscape in Austria-Hungary was compared to the situation in Germany. However, Einstein was returning to Zurich not Germany. There were also suggestions that because Einstein was a Jew he had been treated badly by the education authorities in Vienna and therefore did not wish to stay in Austria. Einstein sent a letter to the ministry of Vienna saying he had no cause for dissatisfaction in Prague. His decision to leave Prague was due solely to the fact that when he left Zurich he promised that he would be pleased to return there under acceptable conditions. In August 1912, Einstein returned to Zurich as a full professor with a top salary grade to the Physical Institute of the Federal Polytechnic, an institute that he cherished.

After arriving back in Zurich in 1912, Einstein stopped using a variable speed of light to describe the gravitational field, as he had attempted to do in 1912 in Prague. Instead, he turned to the metric tensor field, a mathematical object of ten independent components that characterize the geometry of space and time. Einstein needed Marcel Grossmann's help to proceed in his search for a gravitational theory at the basis of which was the fundamental metric tensor. Einstein asked Grossmann to help him solve this gravitational problem by providing him with mathematical tools. Grossmann was happy to collaborate on the problem of gravitation with Einstein (Einstein 1955, 15-16). Grossmann searched the literature, and brought the works of Bernhard Riemann, Gregorio Curbastro-Ricci, Tullio Levi-Civita and Elwin Bruno Christoffel to Einstein's attention.

With Grossmann's help Einstein searched for gravitational field equations for the metric tensor, which stayed covariant under non-linear coordinate transformations. The law of motion of material points in the gravitational field was provided by the geodesic line equation. Einstein detailed his struggles with the new mathematical tools Grossmann brought him, in a small blue notebook – named by scholars the *Zurich Notebook*.

Einstein became fascinated with Riemann's calculus, and he filled 43 pages of this notebook with calculations. He continued to receive new mathematical tools from Grossmann, whose name he jotted in the notebook to indicate which tensors were received from him. Grossmann's name was written on top of one of the pages, where Einstein considered candidate field equations with a gravitational tensor constructed from the Ricci tensor; an equation Einstein would return to in his November 4, 1915, paper on general relativity. However, as indicated in the *Zurich Notebook*, he finally chose non-covariant field equations.

Einstein's collaboration with Grossmann led to two joint papers on these limited-covariant field equations: The first of these was published before the end of June 1913. The second, published almost a year later. The first paper was titled "Outline of a Generalised Theory of Relativity and of a Theory of Gravitation", and referred to by scholars as the *Entwurf* (Outline) paper (Einstein and Grossmann 1913). A remark to the paper, written by Einstein, contained the well-known Hole Argument.

Einstein left Zurich in March-April 1914; this ended his collaboration with Grossmann.

4. From Zurich to Berlin

Einstein did not stay long in Zurich. In January 1913, Fritz Haber thought of bringing Einstein to the Kaiser Wilhelm Institute of Physical Chemistry and Electrochemistry in Berlin. The Kaiser Wilhelm Society was an organisation created in 1911 by Kaiser Wilhelm II. Haber wrote to Hugo Krüß, a worker at the Prussian Ministry of Education, that Einstein's closest colleagues were Max Planck, Emile Warburg, and Heinrich Rubens, who also worked in disciplines related to his specialty (Fritz Haber to Hugo Krüß, January 4, 1913, *CPAE* 5, Doc. 428).

Einstein was still unaware of this state of affairs in Berlin (the thought of bringing him to Berlin). At the time, he was at the Zurich Polytechnic working on his new gravitation theory and troubled by various calculations. He was attempting to extract expressions of broad covariance from the Ricci tensor while imposing coordinate conditions. His disappointment led him to attempt establishing field equations while starting from the requirement of the conservation of momentum and energy. Still, Einstein did not fully relinquish. He was trying to find a way to recover the new field equations from the gravitational tensor, the Ricci tensor he had extracted from the Riemann tensor. But, he found it impossible; the next pages in his notebook indicate he was led to non-covariant field equations, which he also established through energy-momentum considerations. Einstein and Grossmann very likely had already prepared a paper for submission relating these non-covariant field equations (the *Entwurf* theory). The time now was late spring 1913.

At the same time, in Berlin, between January and May 1913, the emphasis seemed to have shifted from Haber's original proposal. By late spring, Max Planck and Walther Nernst had modified Haber's proposal, combining the idea of Einstein's membership in the Academy of Prussian Sciences with the prospect of his directorship of the Kaiser Wilhelm Institute of Physics. Einstein would remain in Haber's institute until 1917, and a special membership in the Academy of Prussian Sciences was conferred to him.

To ensure Einstein's election to the Prussian Academy, the four most important German physicists and members of the Academy – Planck, Nernst, Rubens and Warburg submitted a request to the Prussian Ministry of Education (Seelig 1954, 172-173; 1956a, 143-144).

They first announced in the physical-mathematical class of the Prussian Academy of Sciences that they would submit a proposal for membership at the next session. The identity of the candidate was not given. Two weeks later they proposed Einstein for election as a regular member of the Academy.

Max Planck, the presiding secretary of the class, read aloud a text of proposals to the physical-mathematical class on June 12, 1913. The text stated (Proposal for Einstein's Membership in the Prussian Academy of Sciences, *CPAE* 5, Doc. 445; Doc. 1 in Kirsten and Treder 1979, 96-97): Einstein was born in March 1879 in Ulm, raised in Munich, was a citizen of Zurich from 1901, and was employed as a technical expert in the patent office from 1902 to 1909. In 1905 he was awarded his doctoral degree from the University of Zurich, habilitated in 1908 in Bern, accepted an appointment as extraordinary professor of theoretical physics at the University of Zurich in 1909, and an ordinary professor at the German University in Prague the following year. From there he returned to Zurich, to the Polytechnic in 1912.

Planck noted that thanks to Einstein's papers in the field of theoretical physics, published for the most part in the *Annalen der Physik*, Einstein achieved at a young age, within the circle of his specialty, a worldwide reputation. His name became widely known in his famous 1905 treatise on the electrodynamics of moving bodies, which established the principle of relativity.

However, Planck informed the attendants that as fundamental as this idea of Einstein's has proved to be for the development of the principles of physics, its applications were, for the present, still at the very limit of the measurable.

Planck mentioned Einstein's tackling of other central questions that proved to be much more meaningful for applied physics. He was the first to demonstrate the significance of the quantum hypothesis for the energy of atomic and molecular motions; he derived from this hypothesis a formula for the specific heats of solid bodies.

Planck summarised his proposal to the physical-mathematical class by saying that, among the major problems with which modern physics was so rich, there was no one in which Einstein did not take a position in a remarkable manner.

However, Planck added that Einstein in his speculations, occasionally, overshot the target, as for example in his light quantum hypothesis. This should not be counted against him he continued; because without taking a risk, even in the most exact science, one could not be driven to real innovation. In 1905, Planck was co-editor of the *Annalen der Physik*, and he accepted Einstein's paper on light quanta for publication, even though he disliked the idea of light quanta.

In regard to Einstein's theory of gravitation at that time, Planck commented that Einstein was working intensively on his new theory of gravitation; with what success, only the future would tell.

Planck ended his proposal by saying that he and the three undersigned members (Nernst, Rubens, and Warburg) were aware that their proposal to accept so young a scholar as a full member of the Prussian Academy was unusual; but they believed not only that the unusual circumstances adequately justify the proposal, but also that the interests of the academy really required that the opportunity that now manifested itself to obtain such an extraordinary power be taken in its full possibility.

Planck thought that even if they could not guarantee the future, they could be convinced that the recommended previous accomplishments of the nominee fully justified Einstein's appointment to the most distinguished state scientific institute. Additional evidence indicated that the entire world of physics would consider Einstein's entrance to the Berlin Prussian Academy of Sciences as a special gain for the academy.

Louis Kollros, a former classmate of Einstein, wrote that, Planck and Nernst speculated about Einstein as an award-winning chicken-hen, but Einstein was worried he might not be able to lay any more eggs (Kollros 1955, 29-30); because he was probably worried about not being able to find generally covariant gravitational equations.

Planck, however, had the right intuition. Already in 1905, he accepted Einstein's relativity paper for publication in the *Annalen*. He was also the first known scientist to respond to it in 1906. Planck had the feeling that the principle of relativity was the right direction. Now Planck believed that Einstein was the right person. He would not always believe in Einstein's new theory of gravitation, but his first intuition was to bring him to Berlin.